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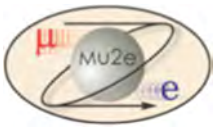

the
Mu2e
project

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Date: 2013-08-26

Analysis of the Distortion of an Uniform Magnetic Field Caused by Magnetic Material

Abstract

This document summarizes the analysis of the distortion of an uniform magnetic field caused by magnetic material immersed into it.

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History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
V1	9/13/13	22	Initial release
V2	9/13/13	22	Update with the DocDB number

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1. INTRODUCTION

The Mu2e solenoid system has been designed to generate a strong magnetic field; its effects can be significant even far from the coils, where some ferromagnetic equipment is present.

In addition to forces which these materials can be subjected to, it is important to have an estimation about the field changes inside and around them, since the consequences of an unexpected increase could be dangerous, especially for electronics.

In this work we estimate the variation of an uniform magnetic field caused by an iron block using 2D FEM simulations done with Opera. 3D simulations including all the equipment and the Mu2e solenoid system would be very time consuming and computationally challenging. We simplified the equipment by a cube and cylinder block.

Figure 1 shows a contour plot on a region 3 m far from the axis of PS (which has the highest field). As can be seen the field gradient is not so steep. Therefore we considered an uniform field in our computation.

We present the results for different objects sizes and in different background fields.

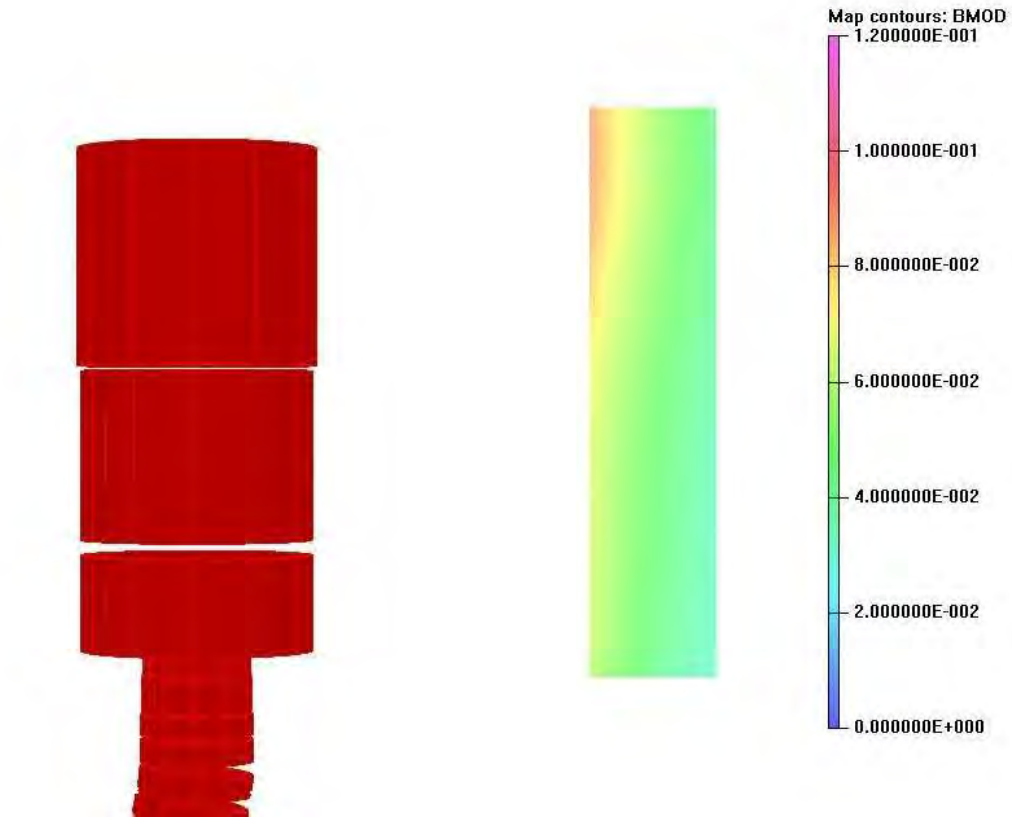

Figure 1 – Area chosen for the analysis

2. VARIATION OF THE FIELD DUE TO A BLOCK

In this section we present the distortion of the magnetic field due to a block made of magnetic material when we vary the size. The background field intensity has been set to 0.06 T. This is the mean value in the region shown in figure 1.

Initially we simulated a constant field and a block made of air (fig. 2). Then we changed the properties of the block to magnetic and observed the distortion of the field lines (fig. 3).

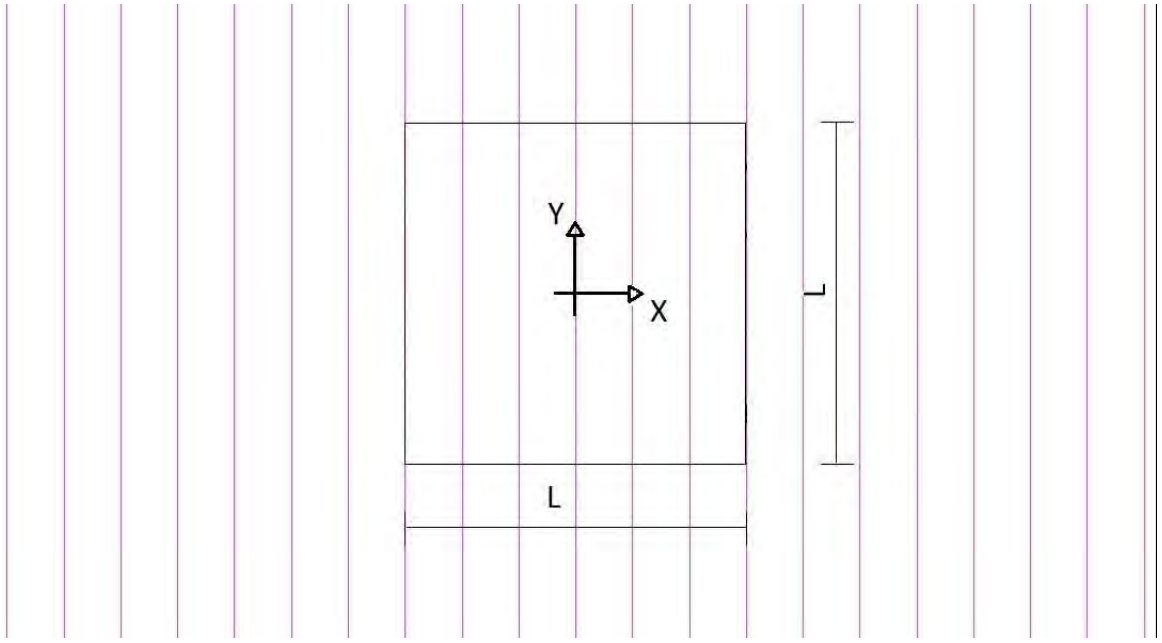

Figure 2 – Field lines, air square.

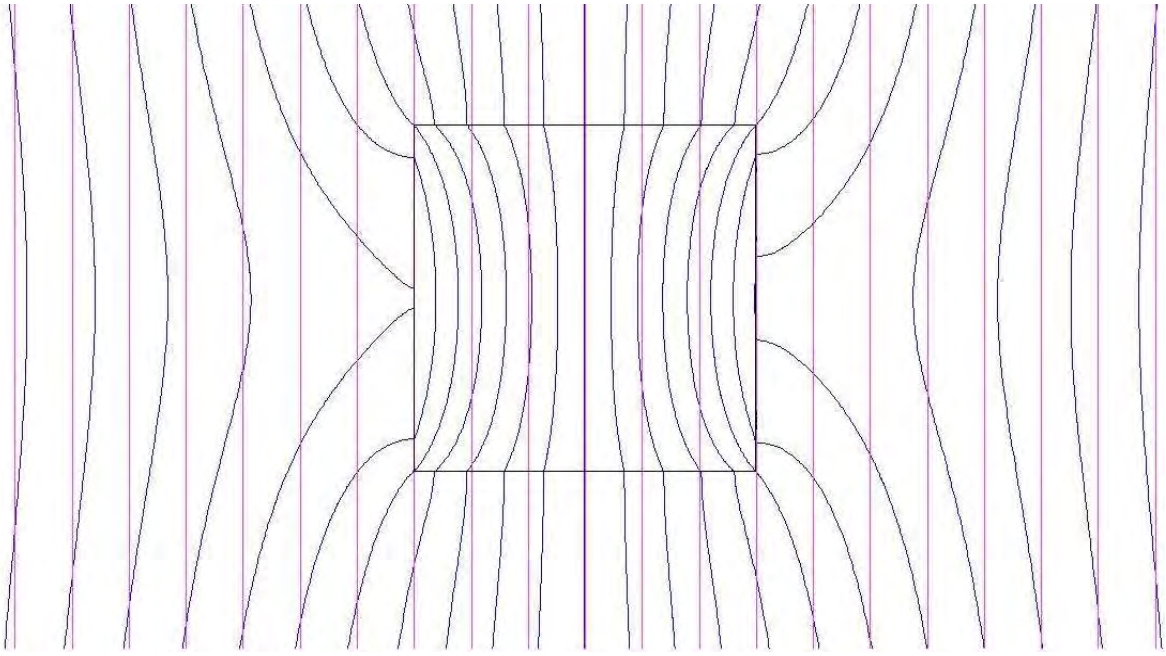

Figure 3 – Field lines: magenta = uniform, blue = distorted.

2.1 CONTOUR PLOTS OF IRON SQUARE BLOCKS WITH DIFFERENT SIZES

It has been analyzed the distortion when an iron block (in this case a square) is immersed in the magnetic field; the length of the square side has been varied from 100 up to 500 mm in steps of 100 mm. The background field was fixed in 0.06 T.

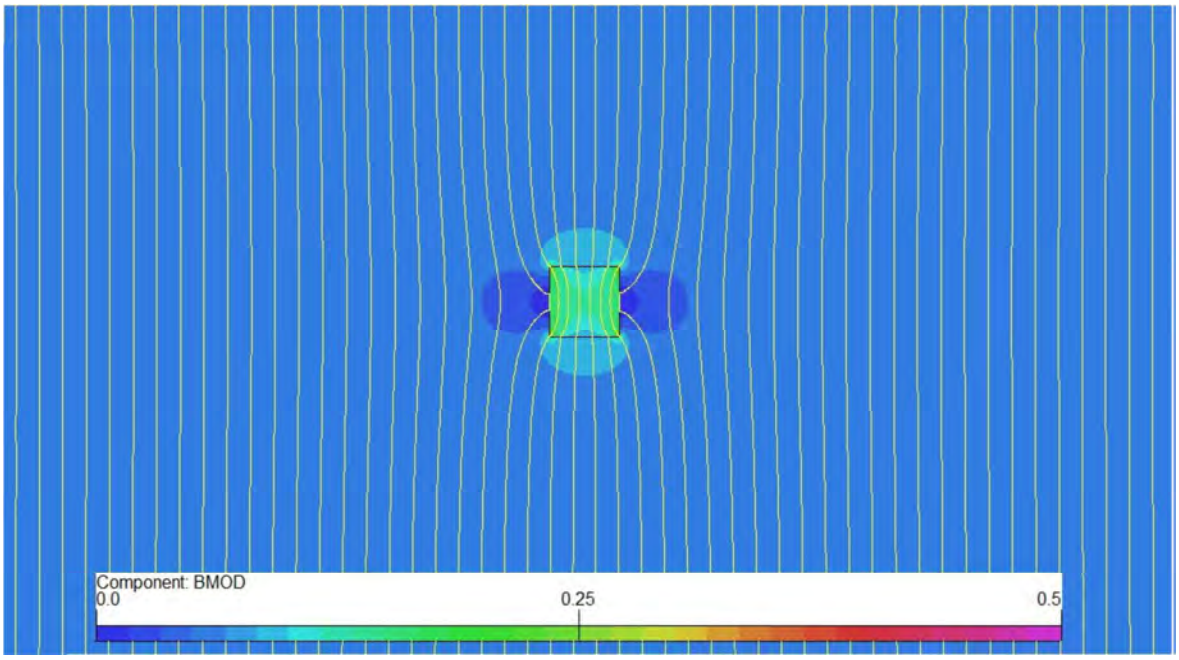

Figure 4 – Contour plot and field lines, L = 100 mm.

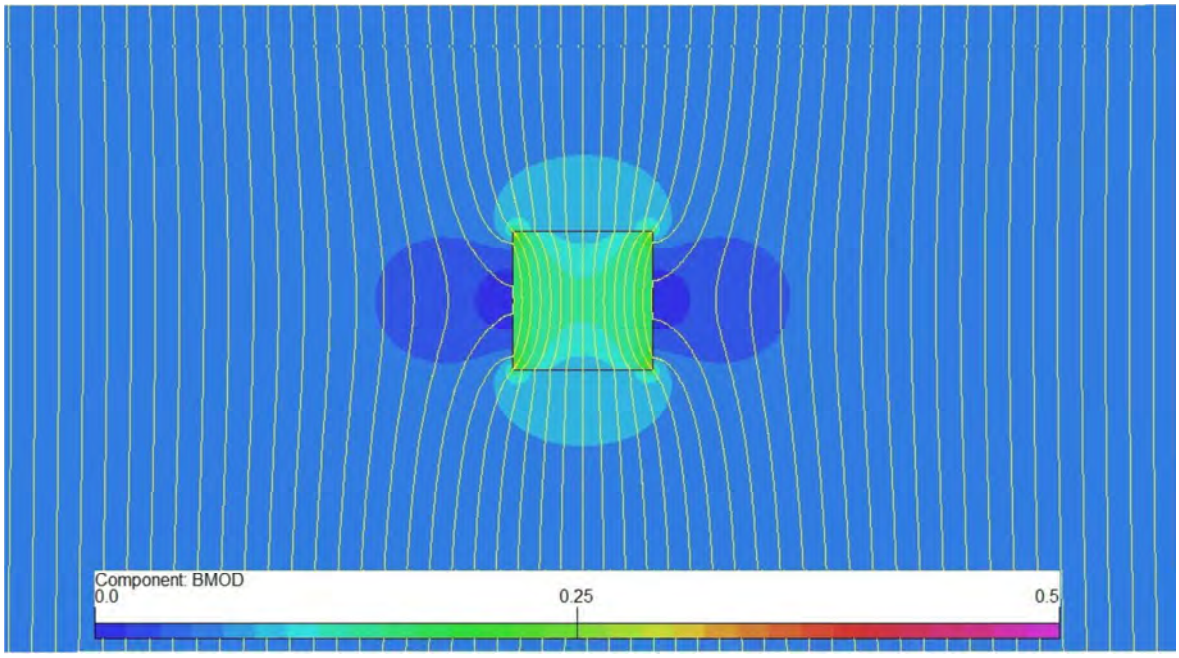

Figure 5 – Contour plot and field lines, L = 200 mm.

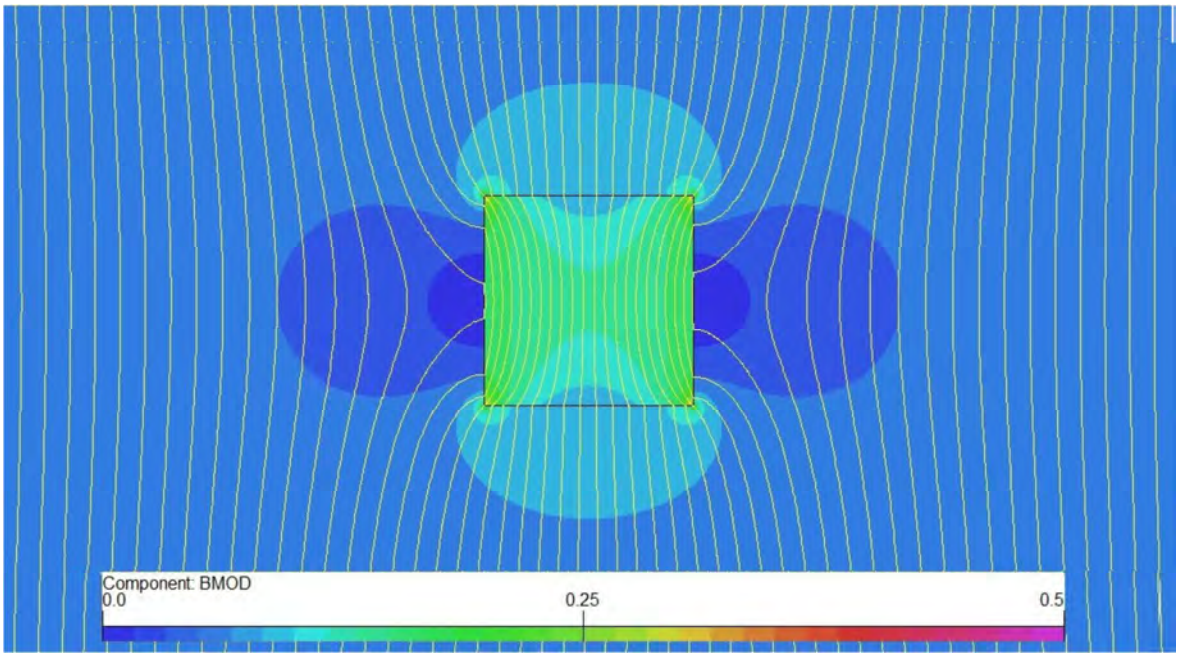

Figure 6 – Contour plot and field lines, L = 300 mm.

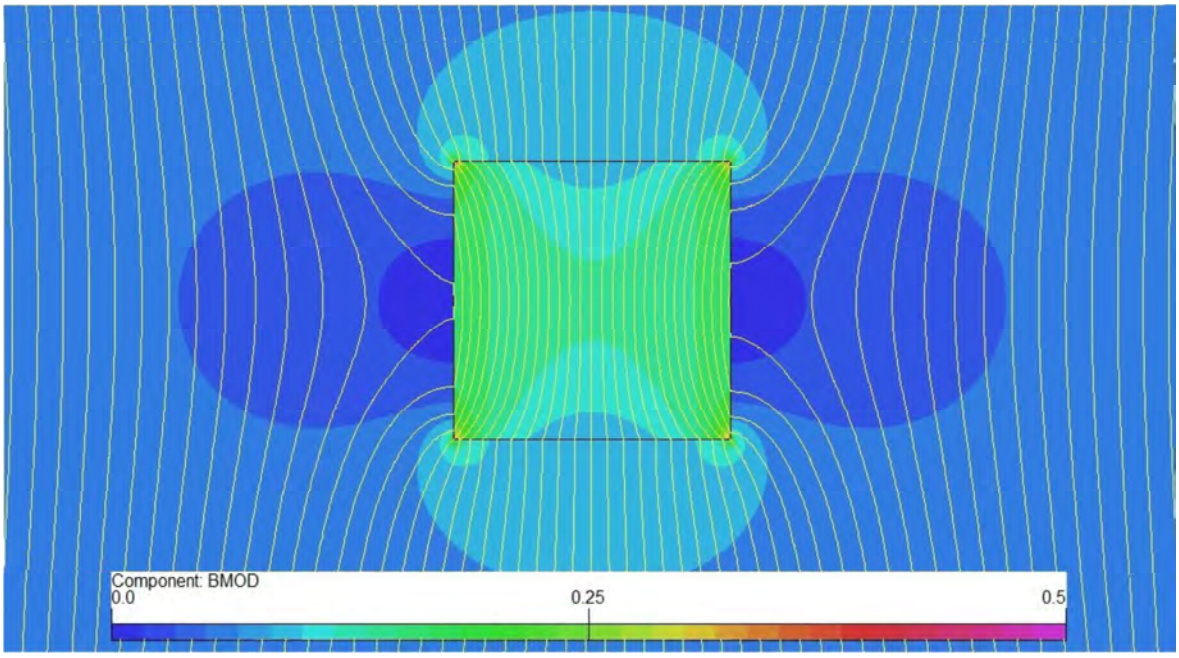

Figure 7 – Contour plot and field lines, L = 400 mm.

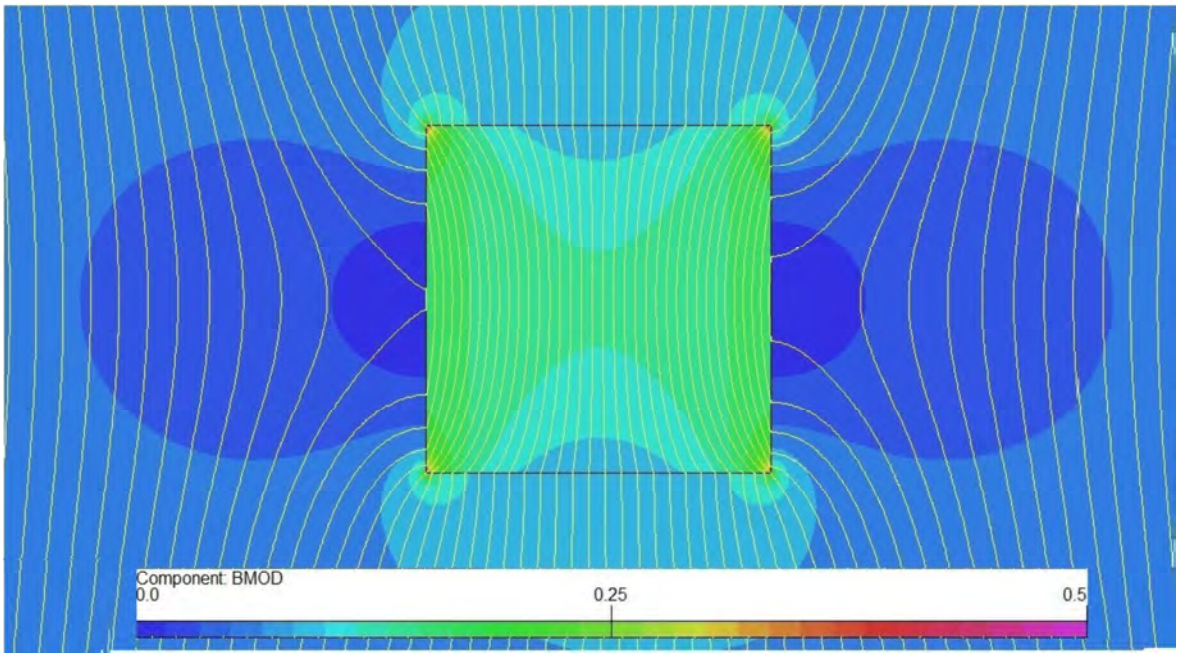

Figure 8 – Contour plot and field lines, L = 500 mm.

2.2 FIELD AT THE CENTRE OF THE SQUARE BLOCK

Fig.9 shows the magnetic field at the centre of the square block. The field is constant within 0.8%.

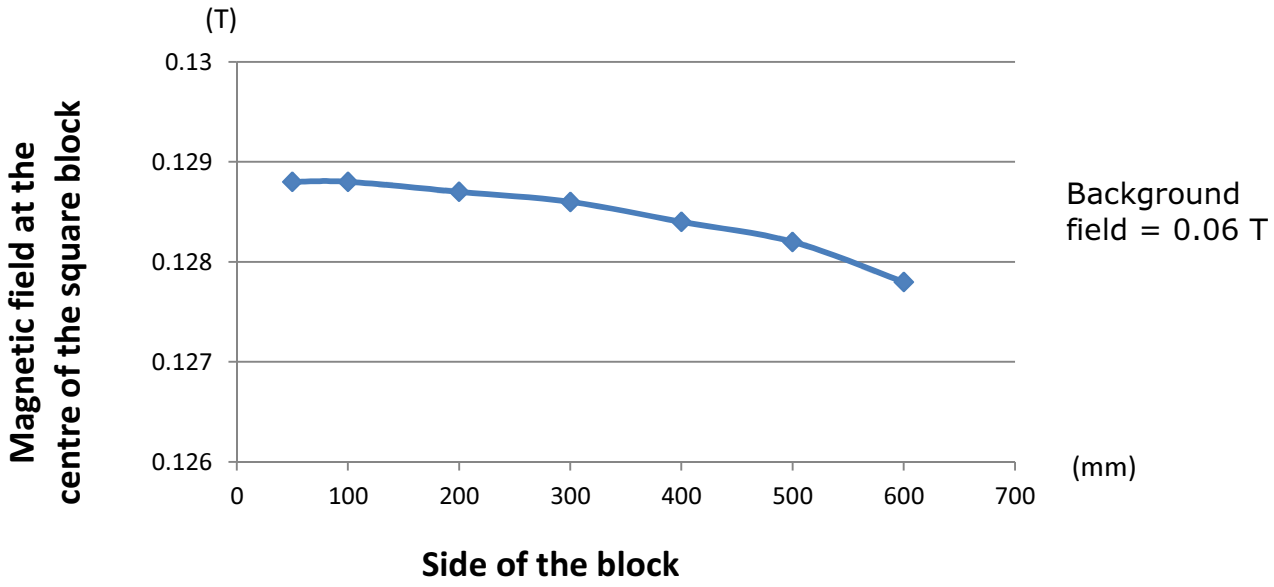

Figure 9 – Intensity of the magnetic field at the centre of the square vs. the side of the square.

2.3 EFFECTS OF THE SINGULARITY

On the previous plots, the peak of the field is located at the vertex of the squares but the value is not reliable because it depends on the size of the mesh, as proved by a refined model. Singular points can be eliminated rounding the vertices. As can be expected, the result depends on the radius of this fillet.

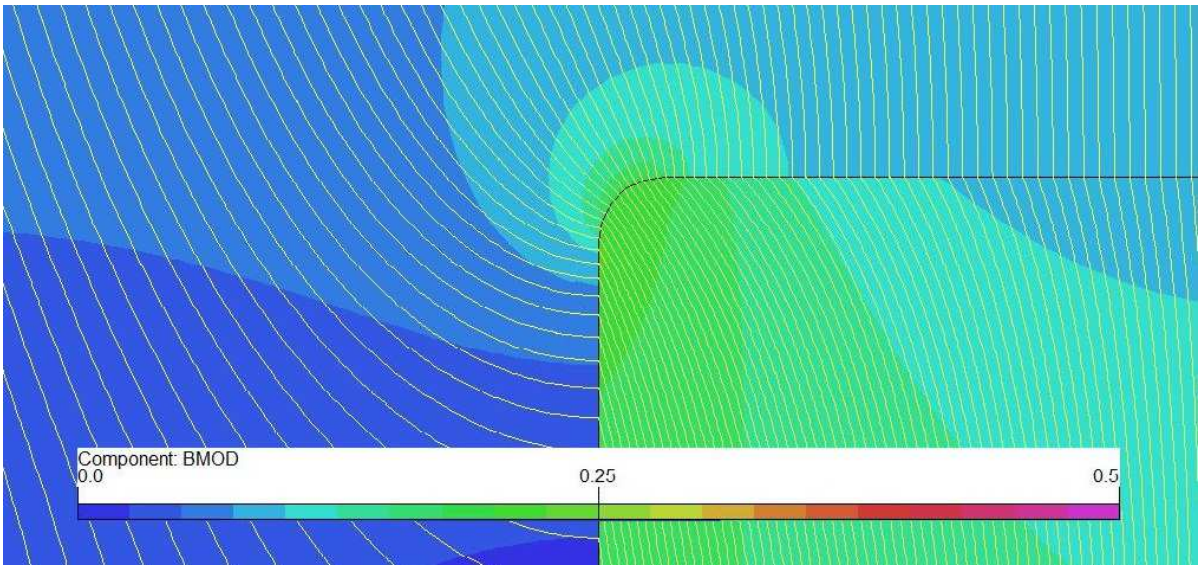

Figure 10 – Contour plot and field lines, zoom on the fillet radius (10 mm).

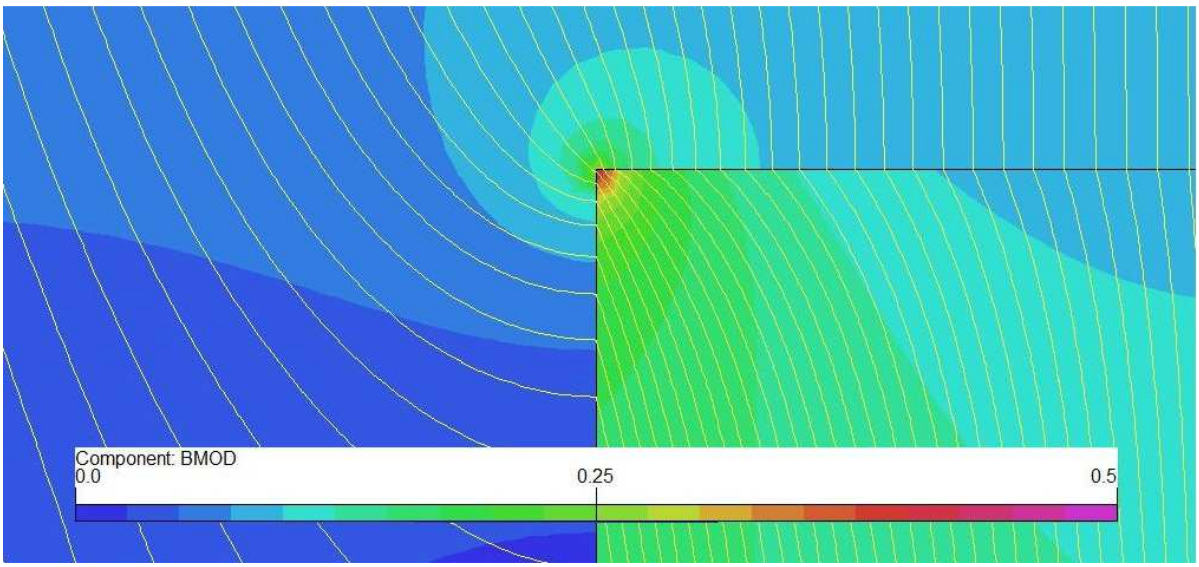

Figure 11 – Contour plot and field lines, zoom on the vertex.

2.3 CONTOUR PLOTS OF CYLINDRICAL IRON BLOCKS

The analysis has been repeated for cylindrical blocks; the diameter has been changed from 100 mm up to 500 mm in steps of 100 mm. As can be seen, the field is uniformly distributed.

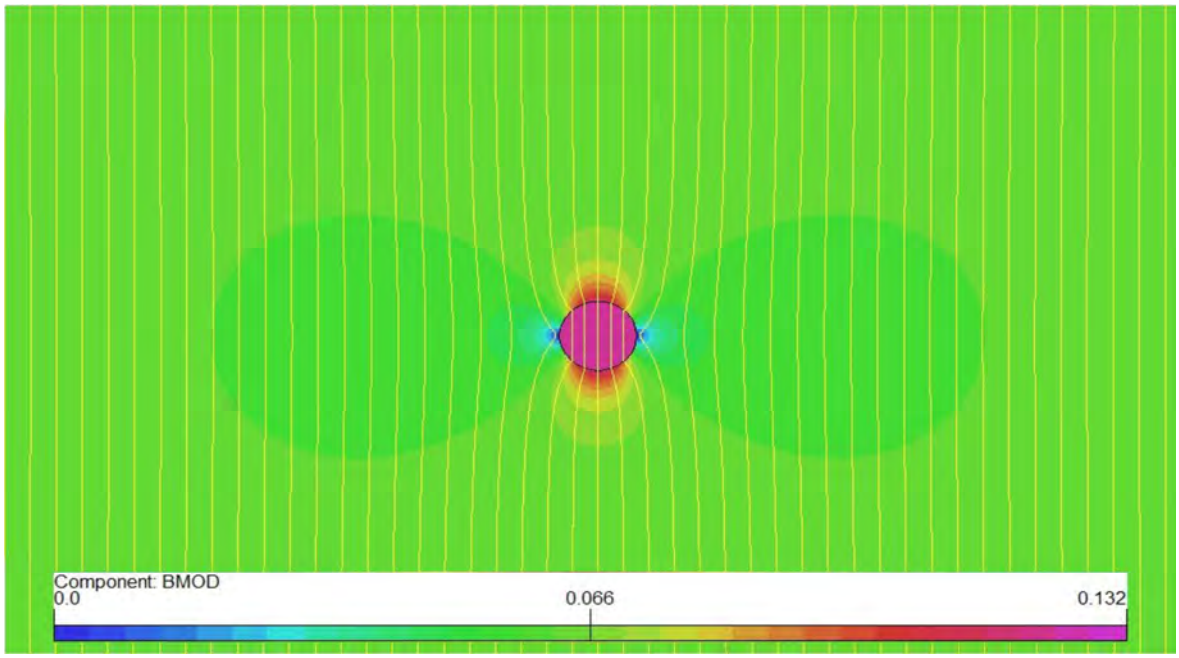

Figure 12 – Contour plot and field lines, diameter of 100 mm.

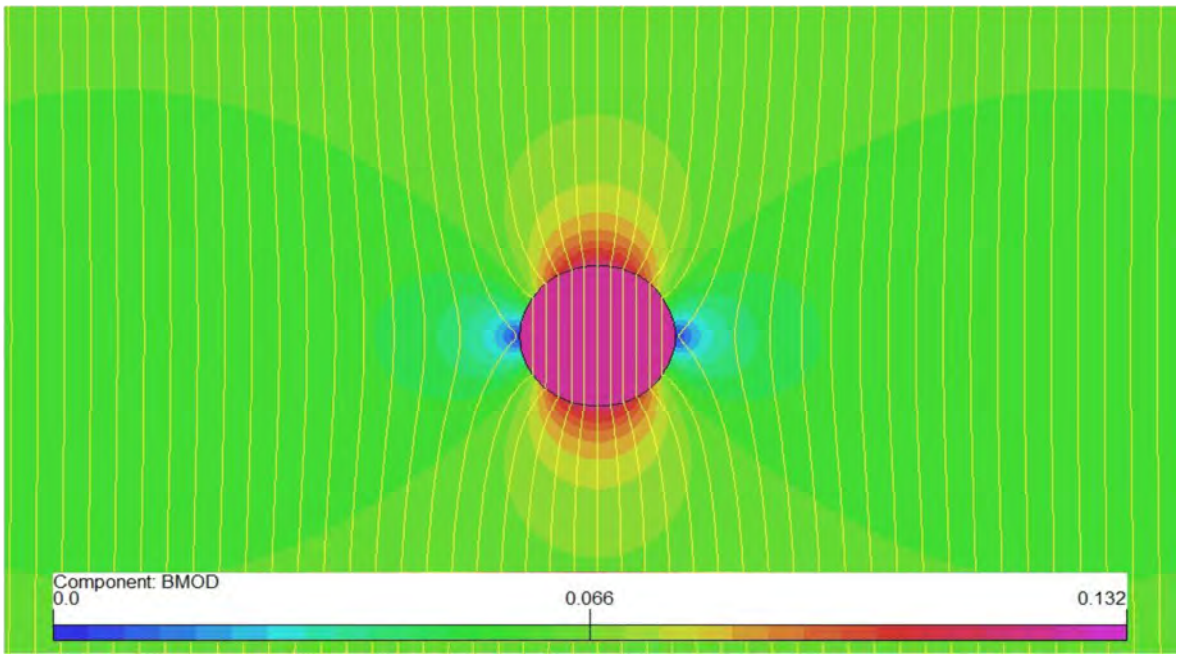

Figure 13 – Contour plot and field lines, diameter of 100 mm.

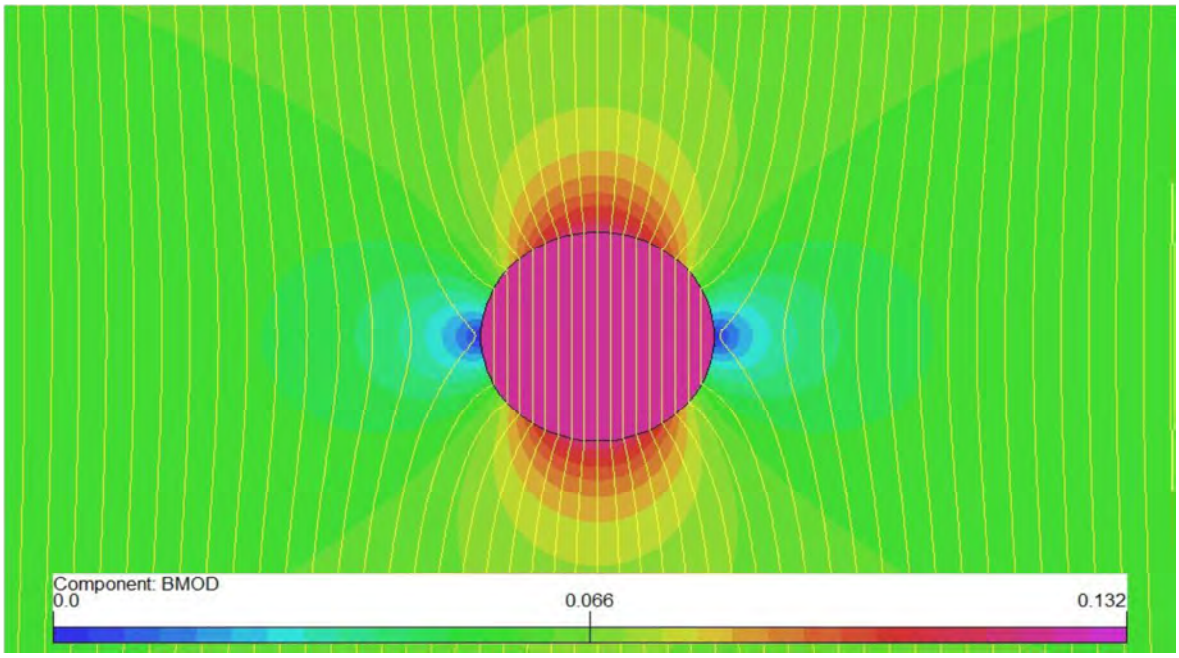

Figure 14 – Contour plot and field lines, diameter of 300 mm.

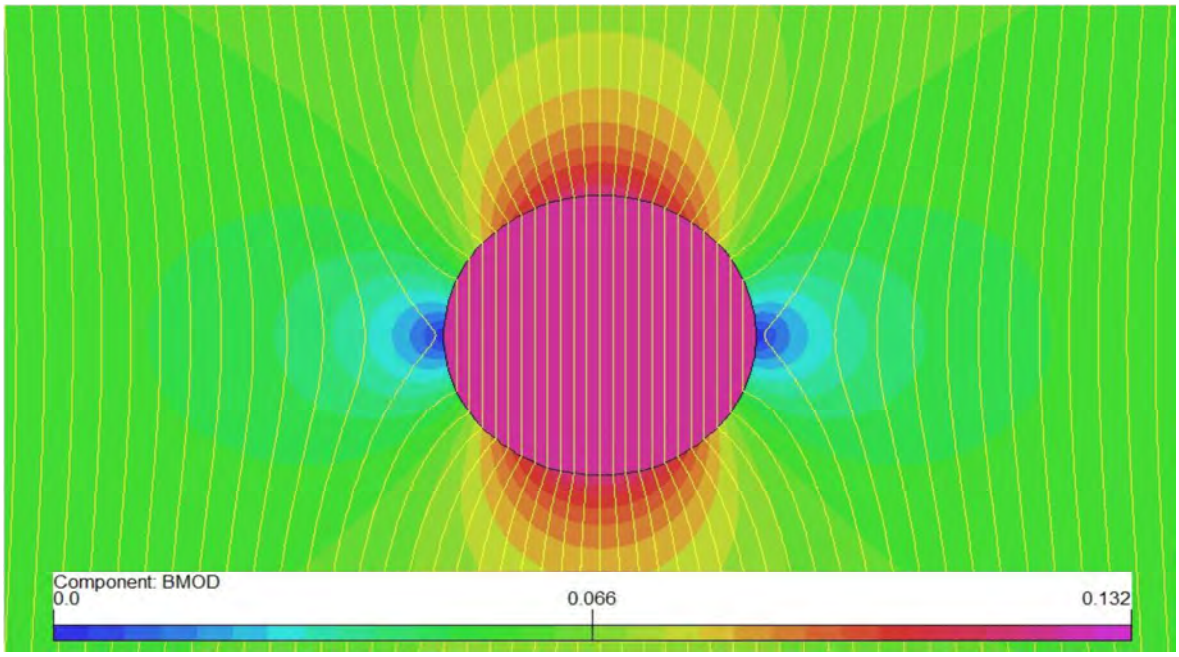

Figure 15 – Contour plot and field lines, diameter of 400 mm.

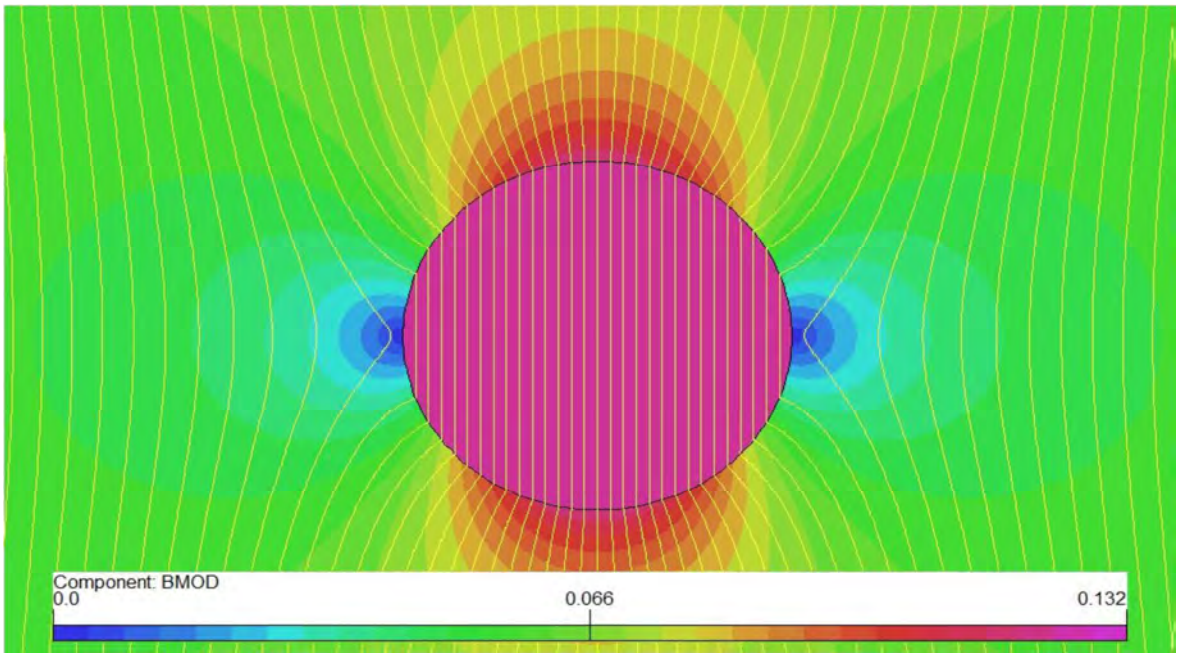

Figure 16 – Contour plot and field lines, diameter of 500 mm.

2.4 FIELD AT THE CENTRE OF THE CYLINDRICAL BLOCK

Fig.17 shows the magnetic field at the centre of the cylindrical block. The field is constant within 0.3%.

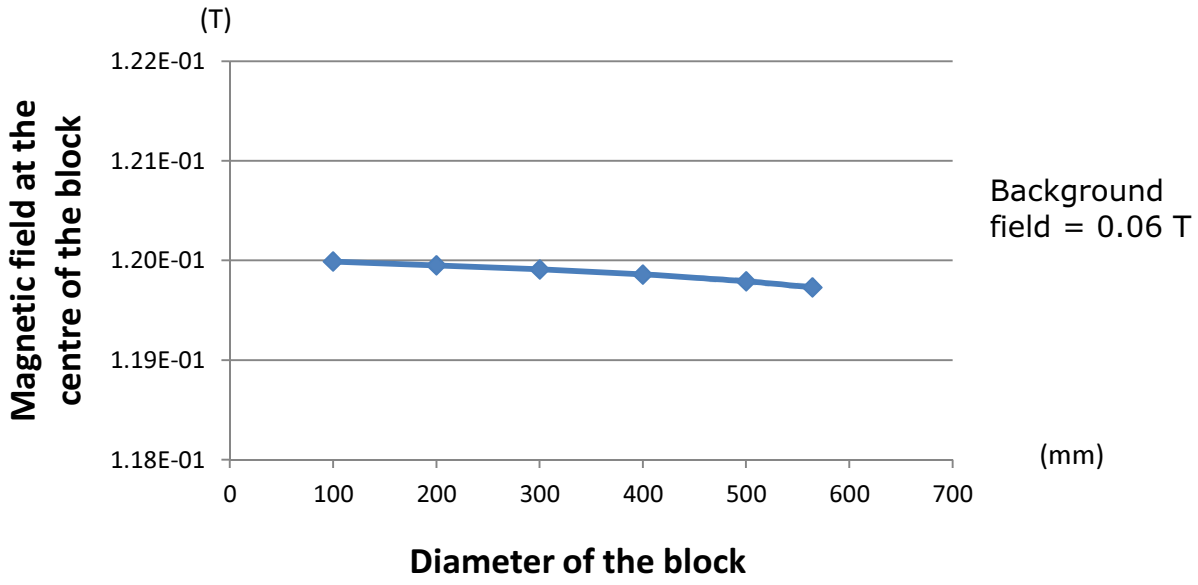

Figure 17 – Intensity of the magnetic field at the centre of the block vs. the diameter of the block.

3. VARIATION OF THE DISTORTION WITH THE FIELD

In this section we present the contour plots of the magnetic fields obtained for a square block with a side of 500 mm when the background field varies.

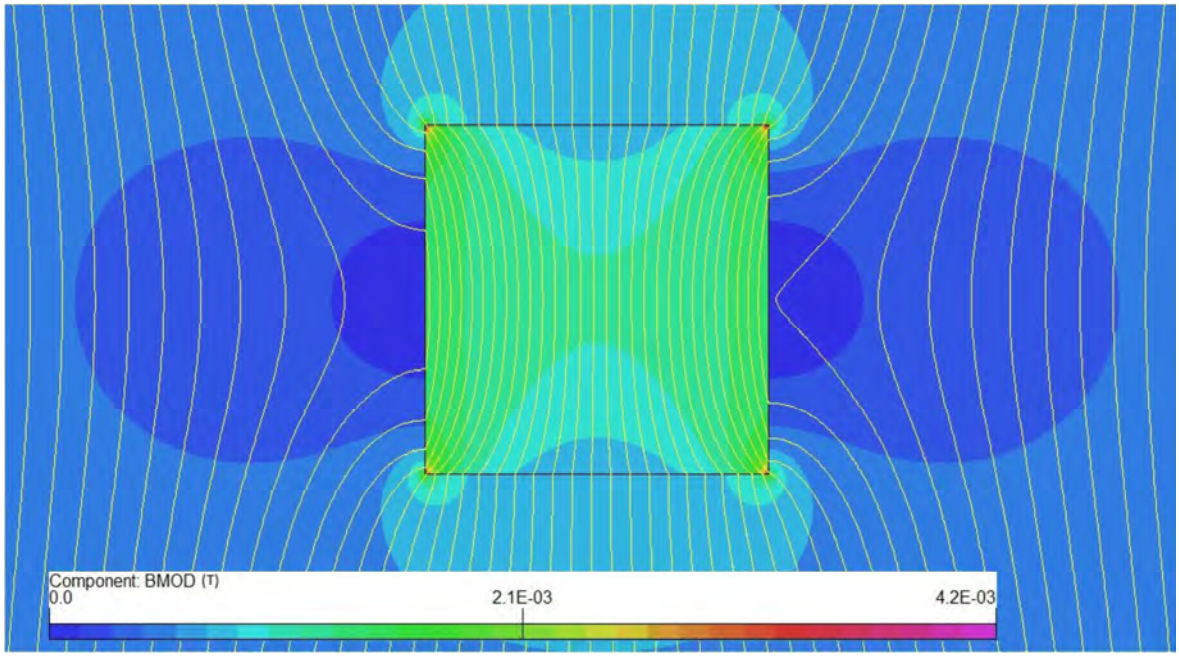

Figure 18 – Contour plot and field lines, field is 5 G.

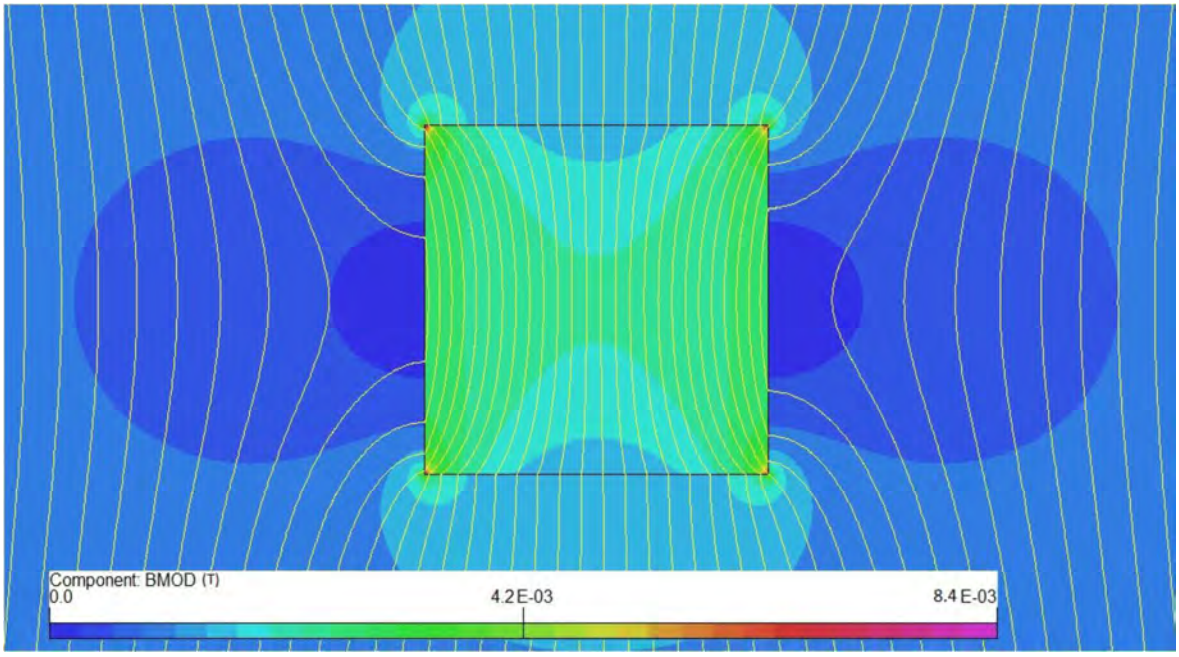

Figure 19 – Contour plot and field lines, field is 10 G.

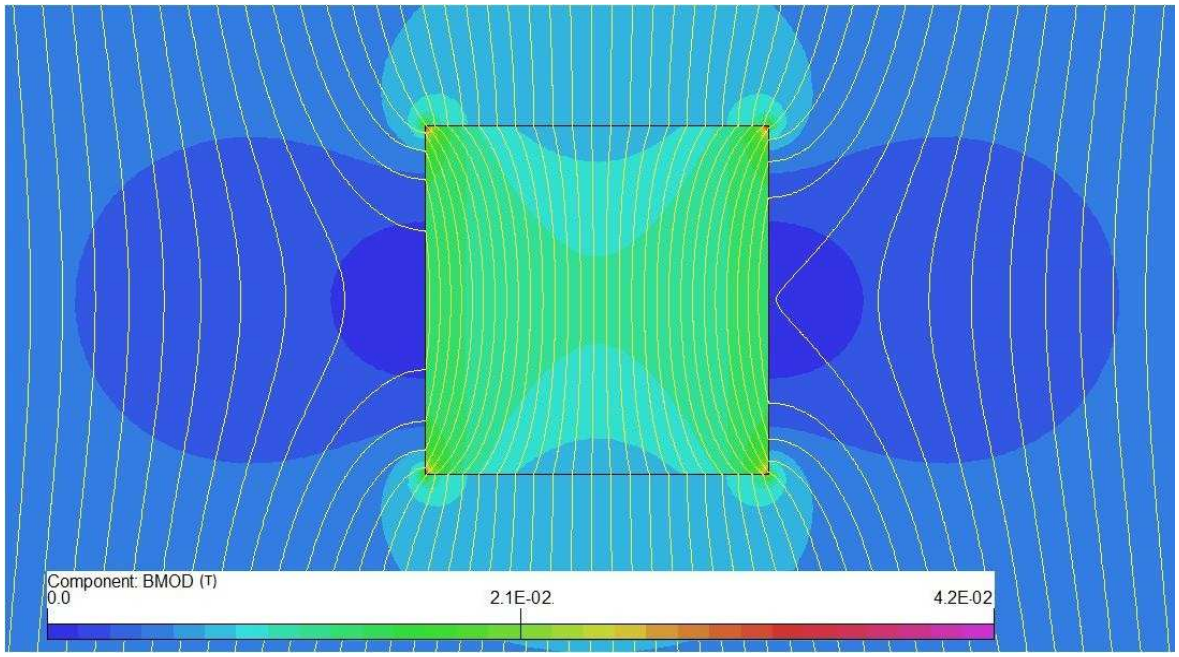

Figure 20 – Contour plot and field lines, field is 50 G

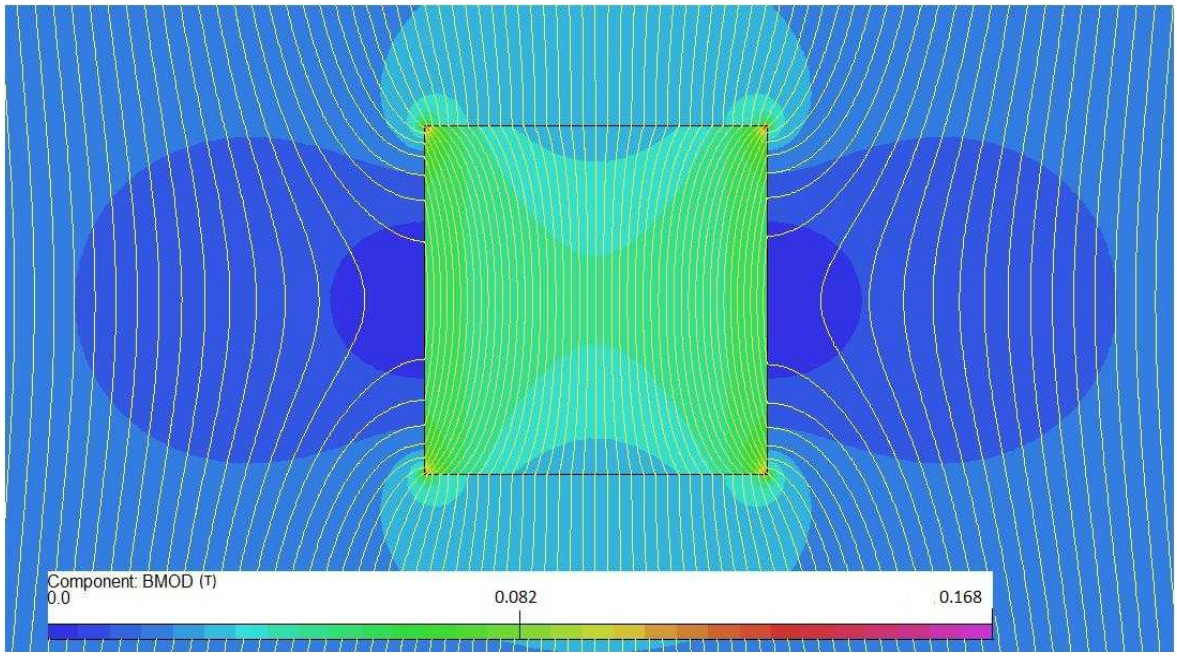

Figure 21 – Contour plot and field lines, field is 200 G

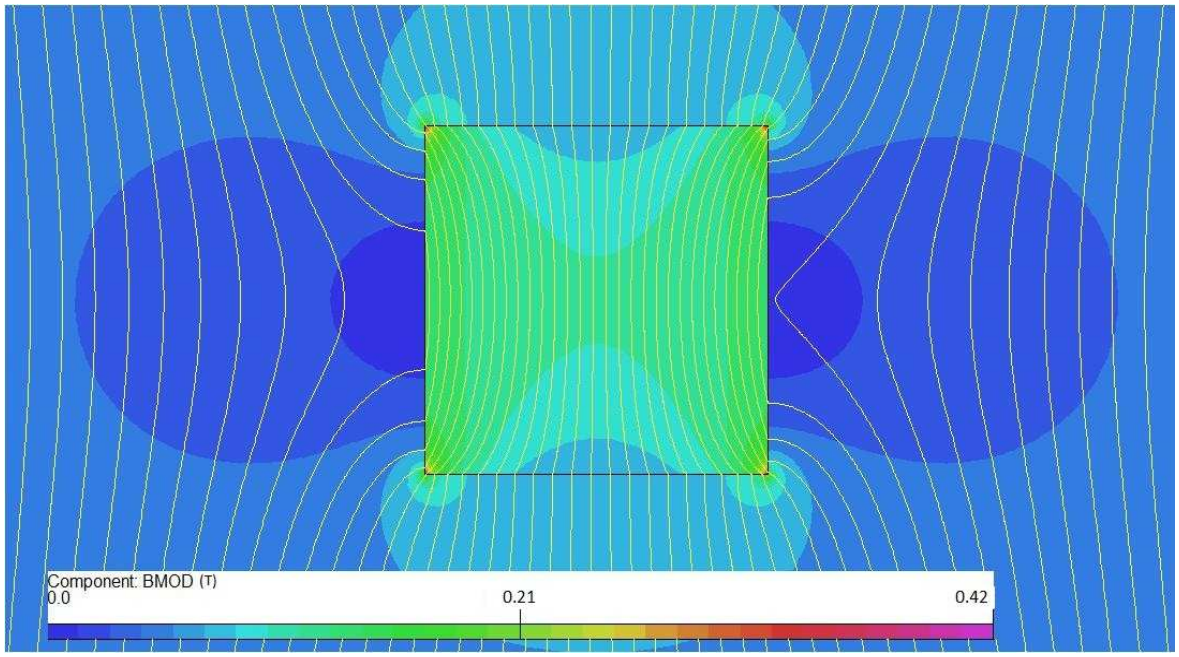

Figure 22 – Contour plot and field lines, field is 500 G

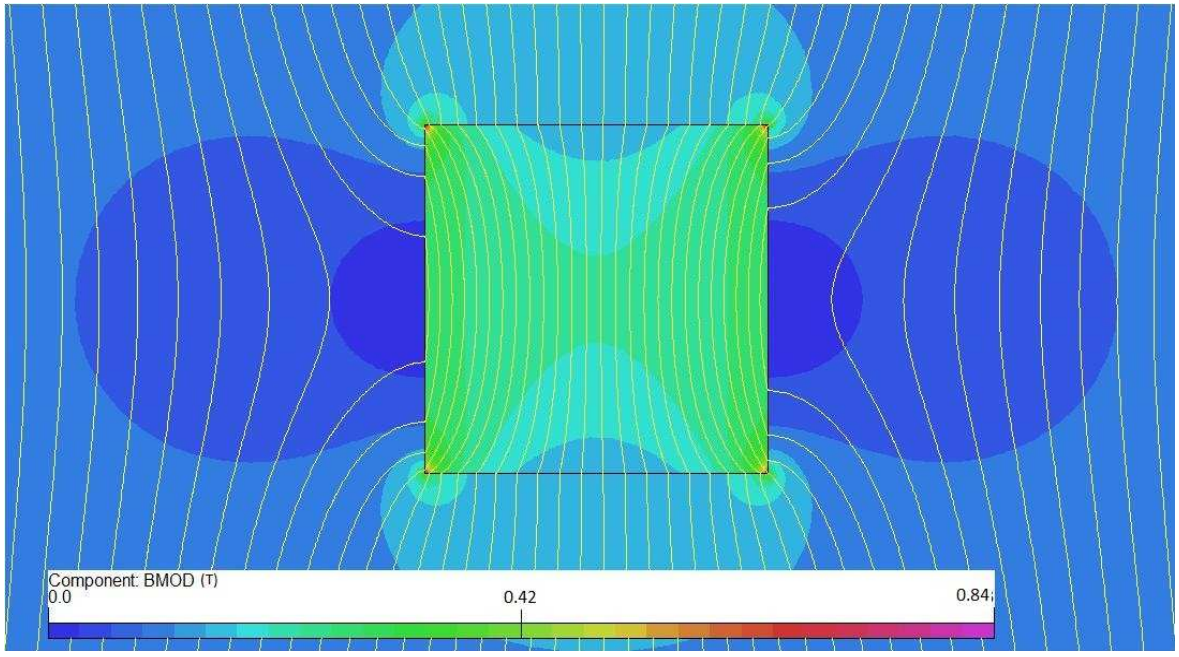

Figure 23 – Contour plot and field lines, field is 1000 G

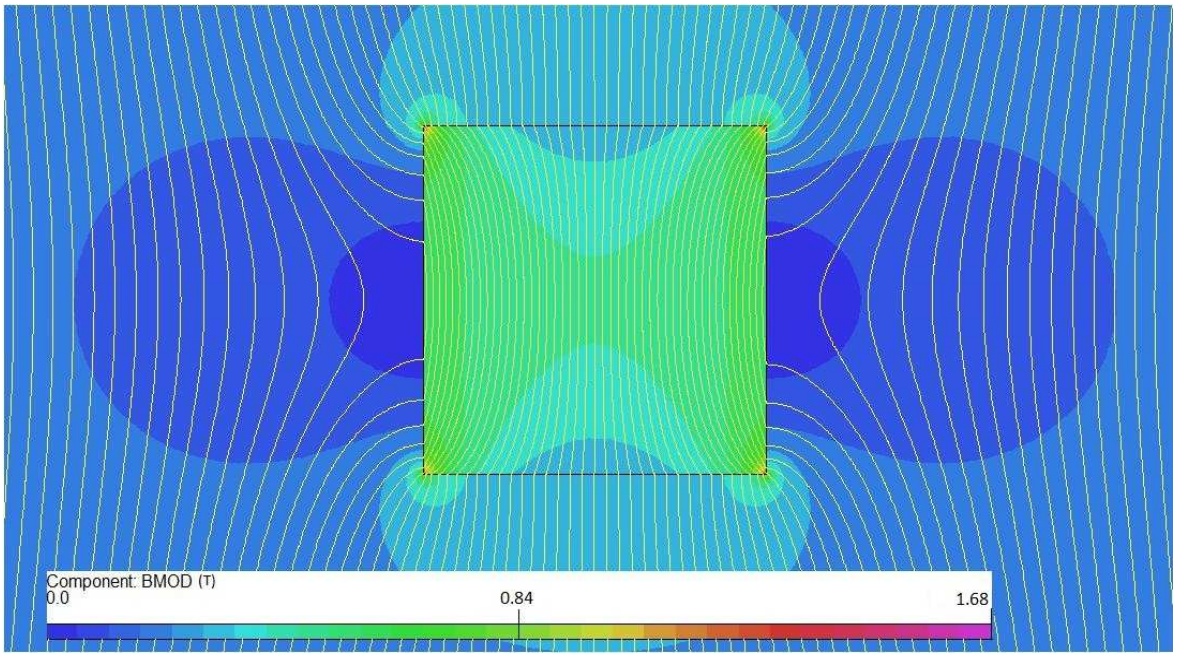

Figure 24 – Contour plot and field lines, field is 2000 G

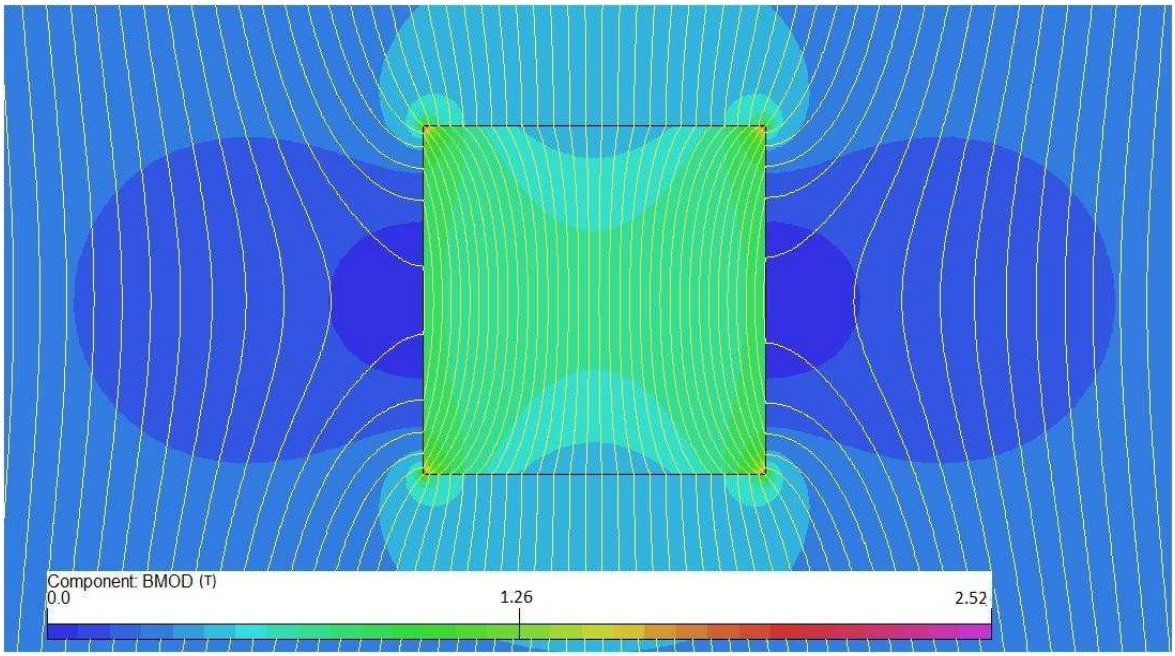

Figure 25 – Contour plot and field lines, field is 3000 G

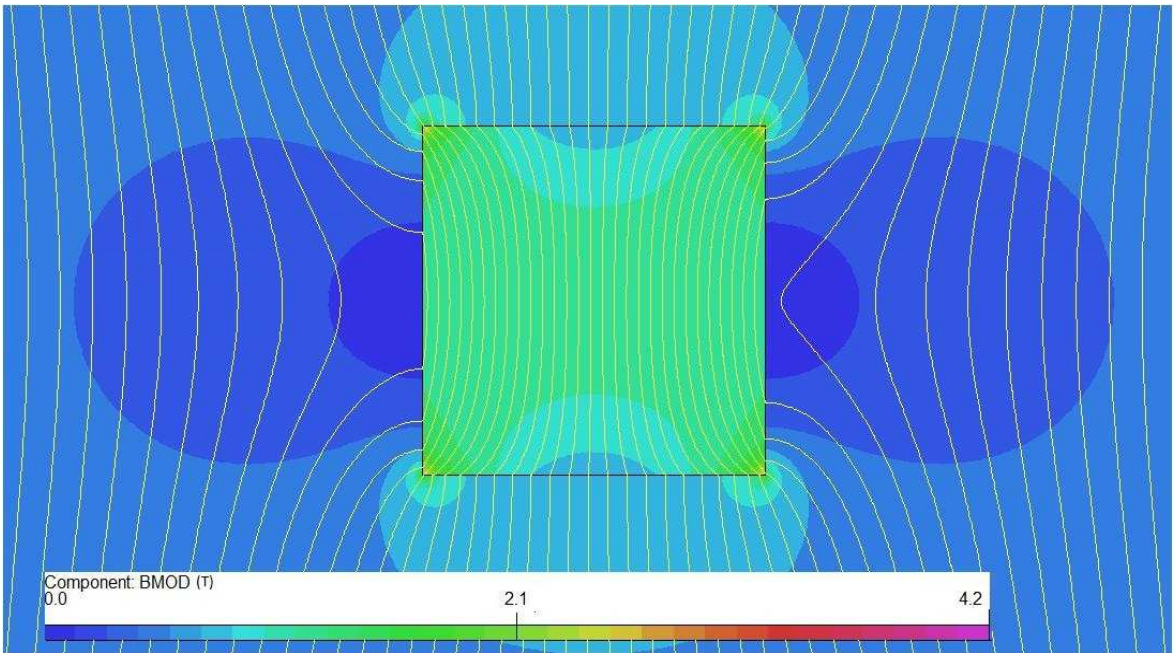

Figure 26 – Contour plot and field lines, field is 5000 G

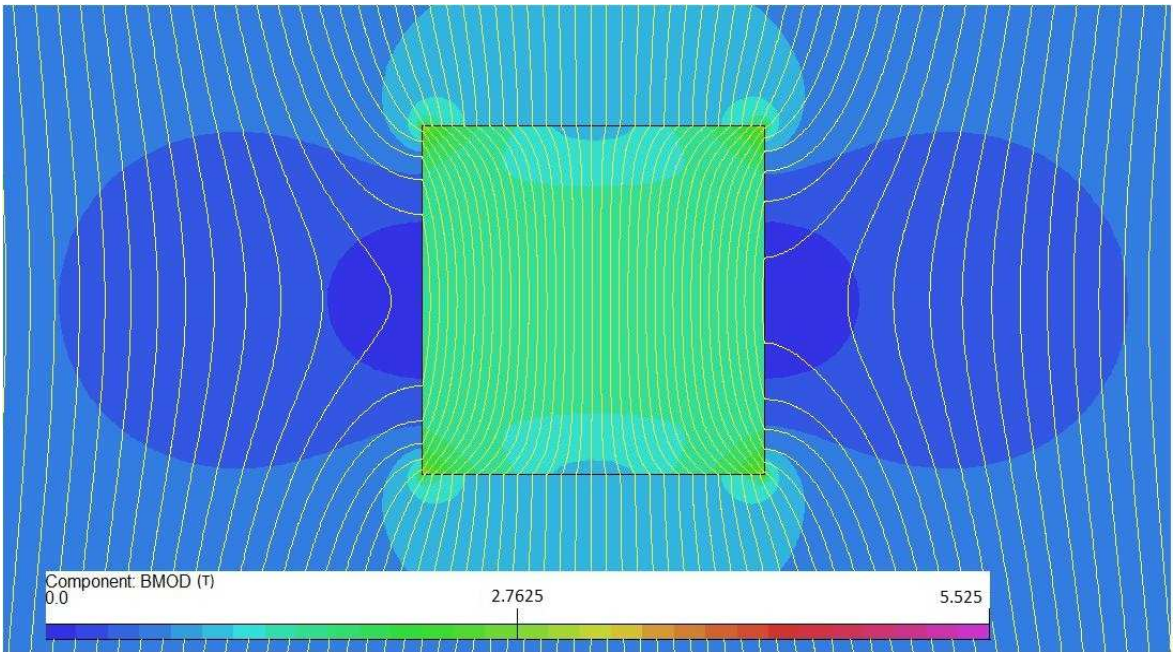

Figure 27 – Contour plot and field lines, field is 6500 G

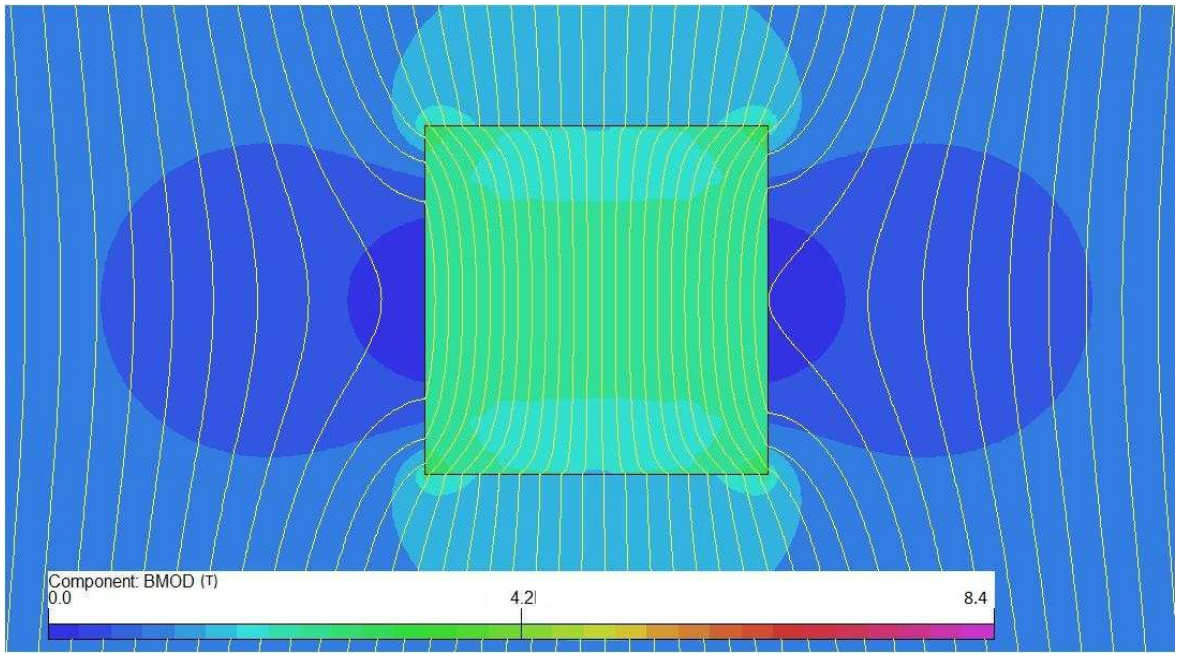

Figure 28 – Contour plot and field lines, field is 1 T.

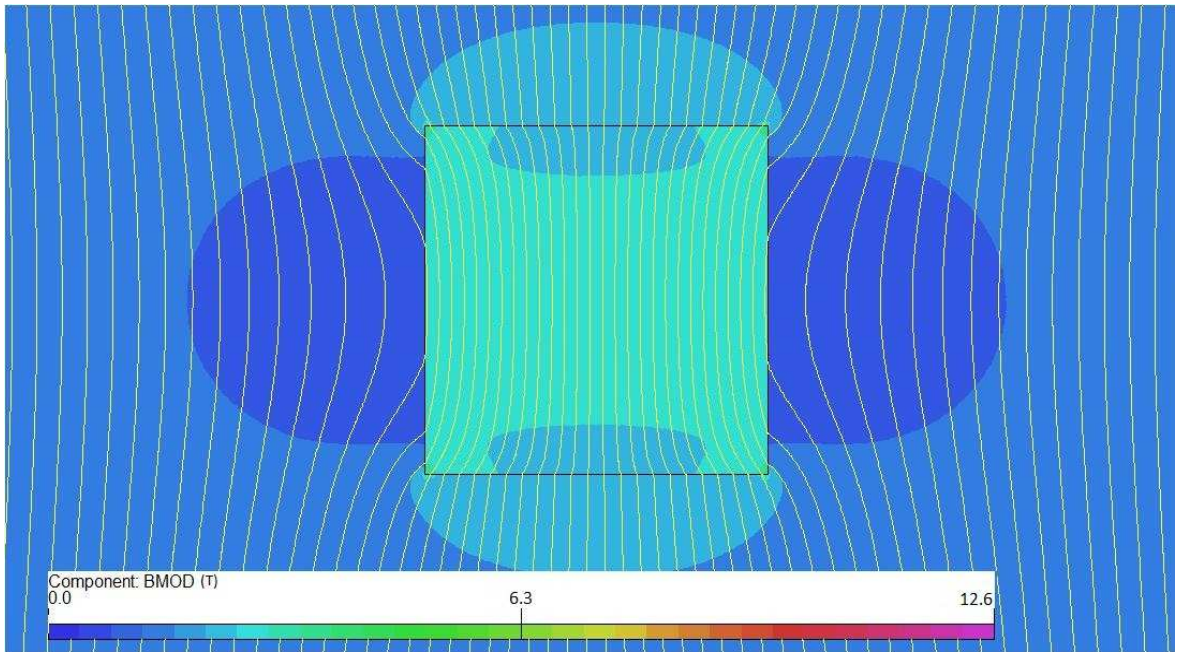

Figure 29 – Contour plot and field lines, field is 1.5 T.

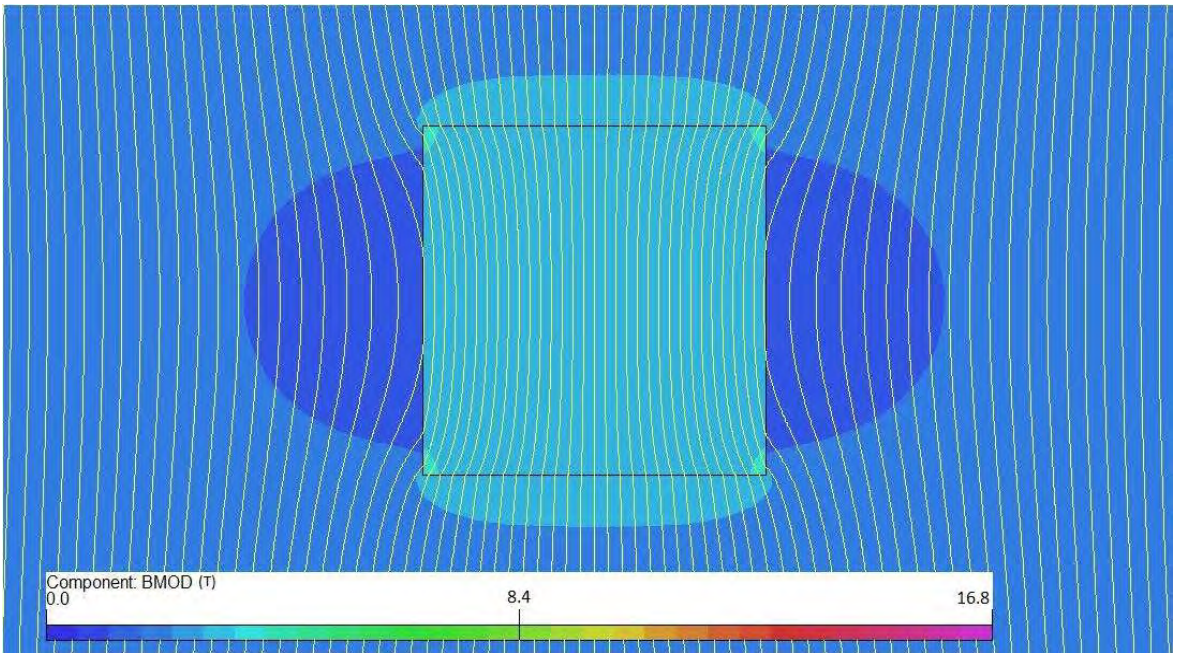

Figure 30 – Contour plot and field lines, field is 2 T.

3.1 MAGNETIC FIELD AT THE CENTRE OF THE SQAURE BLOCK

Figure 31 shows the magnetic field at the centre of the square block variation due to the background field.

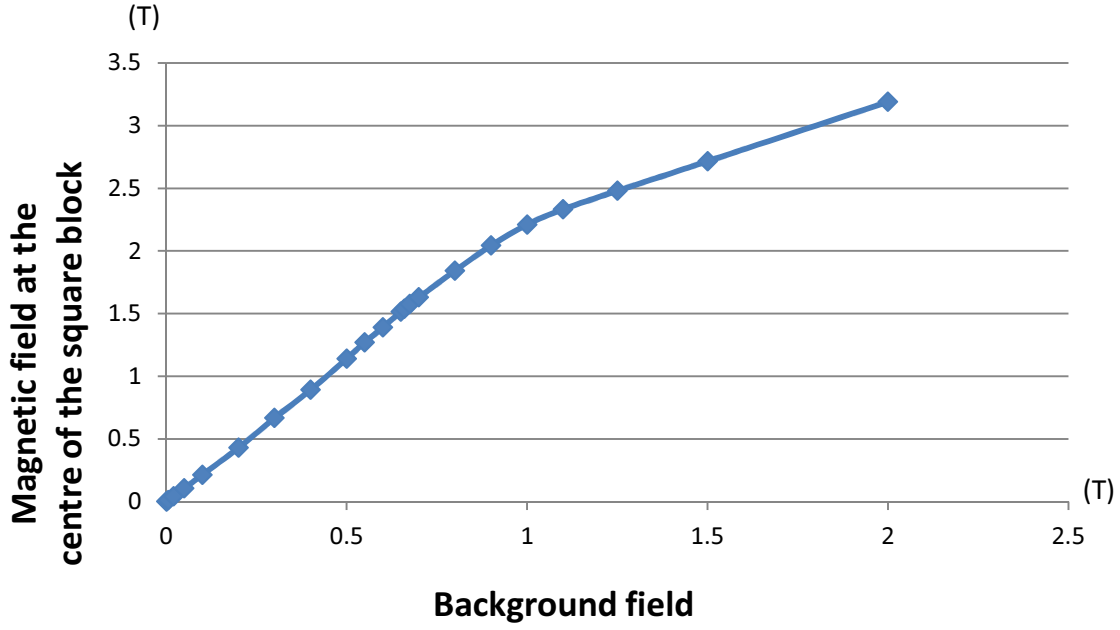

Figure 31 – Magnetic field at the centre of the square vs. Background field.

4. ANALYSIS OF THE DISTORTION

A simple parameter has been chosen to quantify the distortion and it has been called "radius of distortion"'. It is the minimum distance from the surface of the block to where the variation of the field is lower than 5% (the percentage was chosen arbitrarily) taking into consideration the X axis only (defined in fig. 2) due to the chosen symmetry of the study (field lines are parallel to the vertical axis).

Figure 32 shows radius of distortion variation with the area of the block. Figure 33 displays its change due to the background field for four different sizes of the block. Figure 34 presents the modification of this radius with the side of the square block for two values of the background field.

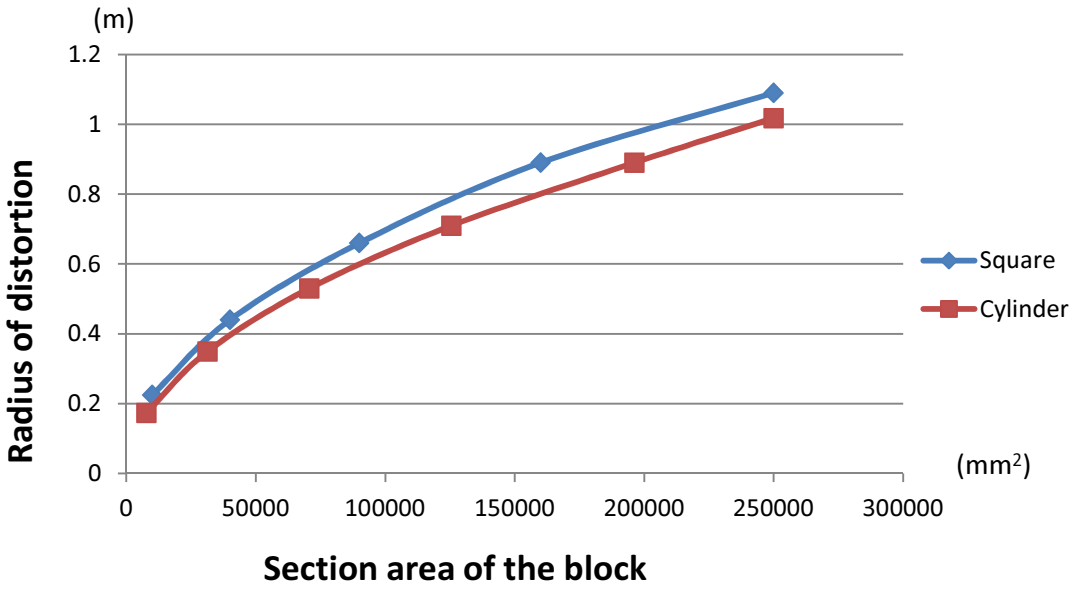

Figure 32 – Radius of distortion vs. size of the body at 0.06 T.

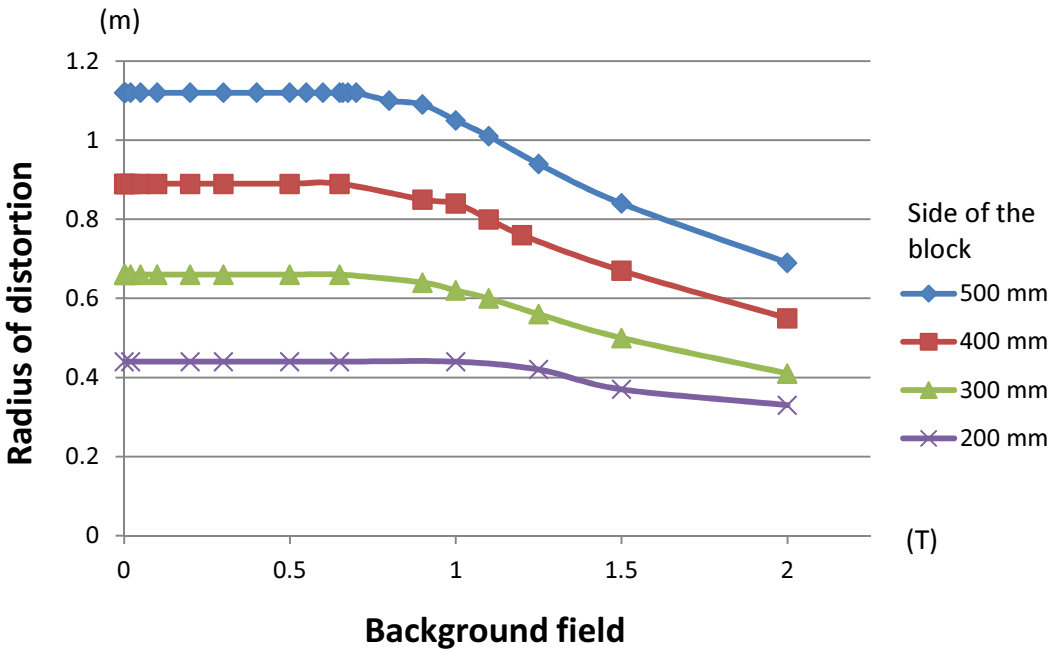

Figure 33 – Radius of distortion vs. background field.

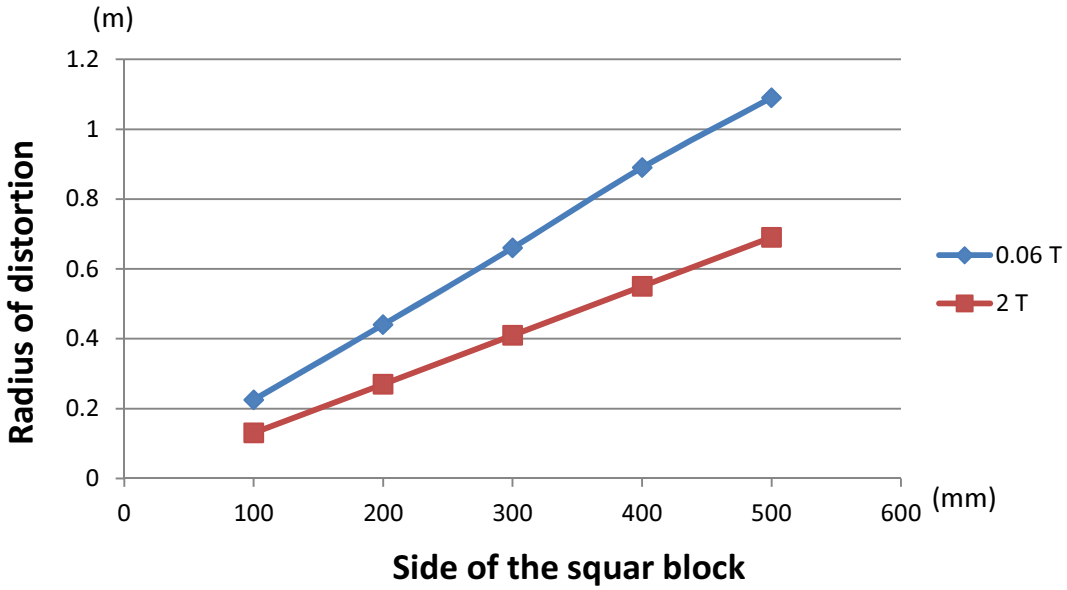

Figure 34 – Radius of distortion vs. size of the body.

5. CONCLUSIONS

The distortion of an uniform magnetic field due to magnetic material has been investigated in several configurations. Singularity of the square block was examined and minimized using round vertices. A parameter to quantify the distortion has been defined and its variations due to the size of the block or to the magnitude of the field have been studied.